Uncertainties and Interdisciplinary Transfers Through the End-To-End System (UNITES)

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Award Number: N0001403WR20208

LONG-TERM GOALS

The overall goals of this research are:
1. To define and characterize the variabilities and uncertainties in the components and linkages of the general physical-geo-acoustical system relevant to the support of naval operations.
2. To transfer quantitatively the spatial-temporal environmental variabilities and uncertainties through the interdisciplinary system, including coupled interactions, in order to determine uncertainty measures, sensitivities and feedback needed to improve operational predictions and parameters.

OBJECTIVES

This effort is part of a multi-institutional team effort, which started in the second half of 2001, to capture uncertainty in the common tactical picture. The team's name is UNITES, which stands for UNcertainties and Interdisciplinary Transfers through the End-to-End System. Led by Abbot, OASIS, Inc., and Robinson, Harvard University (HU), the UNITES team, with expertise spanning the ocean environment, underwater acoustics and tactical sonar systems, consists of a total of twelve principal investigators from nine different organizations including the Naval Postgraduate School (NPS), Woods Hole Oceanographic Institution (WHOI) and University of North Carolina (UNC).

The NPS component in the UNITES team's paradigm to solve the interdisciplinary, end-to-end problem has two objectives:
1. To characterize acoustic prediction uncertainties, including their connections to the uncertainties in the ocean and geo-acoustic parameter estimates.
2. To forecast and improve acoustic baselines and their uncertainties in a data-assimilation framework involving coupled ocean and acoustic state variables.

APPROACH

The research focuses on a shelfbreak environment, encompassing the outer continental shelf and the continental slope, where the physical oceanography, specifically the shelfbreak front, nonlinear internal tides and nonlinear internal waves, play a significant role in introducing acoustic prediction uncertainty at multiple time and space scales. The acoustic prediction uncertainty is further complicated by the variable bathymetry and inhomogeneous sediment properties as the water-column variability shifts the insonified bottom locations from time to time.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2003**	2. REPORT TYPE	3. DATES COVERED **00-00-2003 to 00-00-2003**

4. TITLE AND SUBTITLE **Uncertainties and Interdisciplinary Transfers Through the End-To-End System (UNITES)**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Postgraduate School,,Department of Oceanography,,Monterey,,CA,93943**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

The approach entails both data analysis and modeling utilizing the coupled environmental and acoustic data sets from both Shelfbreak PRIMER and the Asian Sea International Acoustics Experiment (ASIAEX). The Shelfbreak PRIMER data set, obtained in the Middle Atlantic Bight (MAB) shelfbreak region during the summer of 1996, is utilized first to gain fundamental insights into uncertainty transfer and characteristics, and to test and refine methodologies and the associated computer codes for linking and integrating ocean, acoustic and sonar models and data. The ASIAEX data was collected in May of 2001 in the northeastern South China Seas (SCS) with enhanced resolution in the environmental (both ocean and geo) parameters as well as the acoustic wavefields. In the final two years of this effort the techniques developed in the previous years will be applied to the ASIAEX data to capture and characterize acoustic prediction uncertainty in the SCS shelfbreak region that are geographically and dynamically different from the Shelfbreak PRIMER site. Comparison between the acoustic prediction uncertainty characteristics for the MAB and SCS shelfbreaks will be conducted to resolve differences, similarities and dependency. This understanding is crucial to the design of sonar tactics such as optimum selection and placement of sonar systems for different types of shelfbreak regimes.

In acoustic prediction uncertainty characterization and linkage, the NPS work is closely tied to that of OASIS, UNC, WHOI and HU. Depending on the space and time scales, probability density functions (PDF's) of uncertainties in the acoustic variables, such as transmission loss (TL), intensity and travel time, are either estimated from observed environmental and acoustic data or based on Monte Carlo simulation using the Harvard Ocean Prediction System (HOPS) ocean realizations and UNC's geo-acoustical parameter realizations. Climatological data and first-order bottom models are used to define the acoustic baselines from which uncertainties are realized. The broadband, coupled normal-mode model of Chiu et al. (1996) is used to perform all sound propagation calculations. The estimated uncertainty statistics are provided to OASIS, who in turn transfers the acoustic uncertainties to sonar performance uncertainties for selected systems. Additionally, these sophisticated data products and model calculations will be used to crosscheck the first-order, but more physically insightful, analytical models, to be developed by WHOI, for acoustic uncertainty statistics and predictability. These simplified moment solutions by WHOI, in turn, will be used to facilitate the development of simple, robust rules-of-thumb.

For acoustic baseline and uncertainty forecast, a coupled ocean and acoustic methodology to assimilate oceanographic and acoustic data into HOPS is to be developed. The basic approach is that of error subspace data assimilation of Lermusiaux and Robinson (1999). The novelty here is that the acoustic variables are treated as additional state variables in the ocean forecast model that is tightly coupled to the acoustic propagation model. The algorithm, therefore, simultaneously tracks, i.e., forecasts, the dominant error/uncertainty structures in both the ocean and acoustic variables, in addition to improving the baselines.

WORK COMPLETED

In acoustic wavefield uncertainty characterization, NPS continued to focus on the tidal and shorter-scale uncertainties in FY03 with the following accomplishments:

- Analyzed the dependence of TL fluctuation statistics on signal bandwidth using both Shelfbreak PRIMER and ASIAEX (SCS) data.
- Performed model simulation of ASIAEX TL fluctuation statistics, compared modeled statistics to measured statistics, and began studying uncertainty in the mean TL prediction.

In acoustic field uncertainty reduction and forecast, NPS continued to focus on the small mesoscale uncertainties. Significant work completed in FY03 in this topic includes:

- Combined Shelfbreak PRIMER SeaSoar and moored data in a data assimilation framework to upgrade daily sound speed profile and TL estimates.
- Examined the sensitivity of the TL estimate to the resolution of the sound speed estimate.

RESULTS

Using data recorded by the vertical line arrays deployed in Shelfbreak PRIMER and ASIAEX, respectively, high-quality TL estimates as a function of time, depth and bandwidth for fixed-range, slope-to-shelf transmissions in the two geographical locations were derived. The statistical characterizations of the TL fluctuations in both the MAB and SCS sites were then accomplished by constructing normalized daily and sub-daily histograms using the resultant TL estimates. These histograms, i.e., probability density function (PDF) estimates, provide two important results:

1. The Statistics of the “narrowband” TL fluctuations is both depth, time and geographically invariant, with a skewed PDF resembling the density of -10 log of a chi-square distribution of two degrees of freedom and having a standard deviation of approximately 5.6 dB. The shape and standard deviation of the resultant PDF for the narrowband are well predicted by the phase-random, multipath model introduced by Dyer (1970).

2. As bandwidth is enlarged, the PDF of TL fluctuation becomes more symmetric, standard deviation reduces, vertical homogeneity is maintained, but time and geographical invariance are not.

Can models replicate the observed bandwidth-dependent statistics of TL fluctuation? To investigate this question, propagation modeling was performed to simulate the repetitive ASIAEX SCS transmissions for May 8, 2001 using the coupled-mode propagation model of Chiu et al. (1996) in conjunction with a realistic, empirical representation of the sound-speed field (Chiu, 2003) that gives a good fit to the temperature time series measured by the cross-shelf environmental moorings. On this day, water-column variability was dominated by nonlinear internal waves with very large amplitudes. The PDF of the modeled TL fluctuations as a function of bandwidth is displayed in Fig. 1. The modeled statistics closely mimics the observed statistics in three aspects: the shape of the PDF, how the shape changes with bandwidth, and the invariance with depth. A discrepancy however exists in the modeled standard deviation. This discrepancy is shown in Fig. 2, where the modeled standard deviation is compared to the measured standard deviation at a receiver depth of 57 m as a function of bandwidth. Note that this modeling effort has primarily concentrated on the “pure volume” effects of internal tides and waves on signal intensity fluctuations. The sediment in the modeling was taken to be a simple, homogeneous half space. Thus, the discrepancy between the measured and modeled standard deviations is attributable to the neglect of the contribution due to the heterogeneous sediment structure.

The modeling results also enabled a study of the bias error. An important finding is that the differences between mean TL and TL in the mean ocean can be large, but the differences decrease as bandwidth increases.

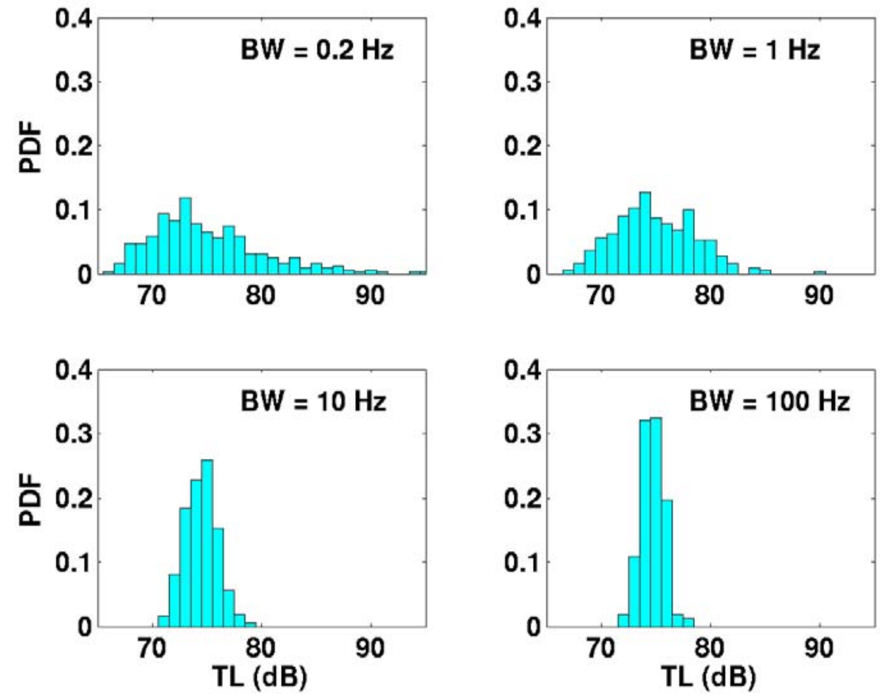

Figure 1. Histograms of modeled transmission loss (TL) for May 8, 2001 versus bandwidth (BW) for the cross-shelf path in the ASIAEX SCS experiment.

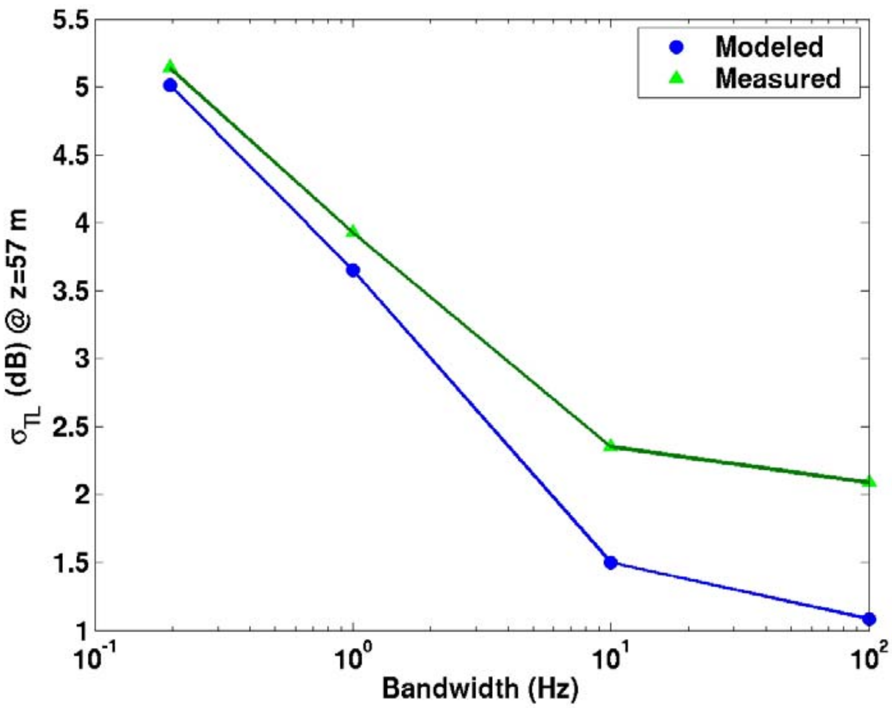

Figure 2. Measured and modeled standard deviations of ASIAEX SCS cross-shelf transmission loss at a receiver depth of 57 m, with the model accounting for "pure volume" effects only.

IMPACT/APPLICATIONS

The characterization of the uncertainties in the ocean and acoustic estimates and the understanding of the linkage of these uncertainties are crucial to the design of sonar tactics such as optimum selection and placement of sonar systems in different environmental regimes.

RELATED PROJECT

This project utilizes the experimental data sets obtained in Shelfbreak PRIMER and ASIAEX.

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